ESTCP
Cost and Performance Report

(MM-0606)

EFFICIENT SHALLOW UNDERWATER UXO RETRIEVAL

October 2009

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

Report Documentation Page					Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.						
1. REPORT DATE **OCT 2009**		2. REPORT TYPE **N/A**			3. DATES COVERED **-**	
4. TITLE AND SUBTITLE **Efficient Shallow Underwater UXO Retrieval**					5a. CONTRACT NUMBER	
					5b. GRANT NUMBER	
					5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)					5d. PROJECT NUMBER	
					5e. TASK NUMBER	
					5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Environmental Security Technology Certification Program 901 North Stuart St., Suite 303 Arlington, VA 22203**					8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR’S ACRONYM(S)	
					11. SPONSOR/MONITOR’S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**						
13. SUPPLEMENTARY NOTES **The original document contains color images.**						
14. ABSTRACT						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT		18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**		**42**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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ACRONYMS AND ABBREVIATIONS

BDU	bomb demonstration unit
BRAC	Base Realignment and Closure
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COTS	commercial off-the-shelf
DIDSON	Dual-Frequency Identification Sonar
DoD	Department of Defense
EOD	explosive ordnance disposal
FEA	finite element analysis
FUDS	Formerly Used Defense Site
GFE	government furnished equipment
GPS	global positioning system
IPR	In Progress Review
LED	light emitting diode
MEC	munitions and explosives of concern
MMRP	Military Munitions Response Program
MRP	Munitions Response Program
MTA	marine towed array
NDCEE	National Defense Center for Environmental Excellence
TNT	trinitrotoluene
UXO	unexploded ordnance

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ACKNOWLEDGEMENTS

This work was funded by the Environmental Security Technology Certification Program (ESTCP) Office under MM-0606, entitled “Efficient Shallow Underwater UXO Retrieval.” We would like to acknowledge Dr. Herb Nelson, Program Manager of ESTCP's Munitions Management Thrust Area, and Dr. Jeff Marqusee, ESTCP Director, for their support, and guidance this project. The Principal Investigator for this project was Dr. Jim McDonald, SAIC. Key technical contributors include Mr. Chris Gibson and Mr. Chet Bassani, SAIC, and Dr. Abed Khaskia, Mallett Technologies.

Technical material contained in this report has been approved for public release.

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1.0 EXECUTIVE SUMMARY

The objective for this project was to design, build, and demonstrate a semi-automated system to provide an efficient, relatively economical, and safe approach for recovering single unexploded ordnance (UXO) targets in shallow water that are buried to deeply in the sediment layer to be recovered by a diver having access only to hand tools. For the purposes of this project, we assume than an underwater UXO survey, analysis, and preparation of a target list has been completed, and that individual target positions have been reacquired for investigation and marked either with flags (very shallow water) or with weights and floats. After the targets have been marked, the recovery process begins.

A work boat is anchored adjacent to the target; it is stabilized by two spuds that are driven into the sediment. A deck crane is used to lower a cylindrical fiberglass shroud onto the target position and a remotely operated water jet/vacuum dredge is used to excavate the sediment from the hole to expose the target. The target is remotely examined using either a TV camera or an imaging sonar system to determine the target's identity and its fuzing. If a supervisory UXO technician determines that the target is safe to recover, it is remotely retrieved using an array of electromagnets.

The project was preceded by an extensive finite element analysis (FEA) modeling study to predict the effects that would result from an unintended detonation of a dud UXO within the shroud. It was concluded that any detonation involving more than 0.4 lb of high explosives would destroy the shroud and all ancillary equipment within the shroud. Using these results the recovery shroud was redesigned to a low cost shroud, which could sufficiently hold removed sediment away from the excavated hole. The blast protection requirement for the shroud design was eliminated.

All mechanical components for the field operational demonstration were then purchased, (or adapted from equipment associated with other projects), or fabricated and then integrated. The various subsystems were tested in the laboratory and in field shakedown studies at local lakes. A Test Plan was developed based upon the assumption that the demonstration would take place on the Currituck Sound on a bombing range near Duck, NC. As we approached final approval of the Test Plan, it was determined that insufficient funds remained in the project to support the full-scale demonstration and completion of the required reports.

As an alternative to the Currituck Sound demonstration, several days of field tests were conducted using the complete system on local lakes (using only inert and surrogate ordnance). These studies were conducted using day trips and without the expensive support of UXO dive teams. All major system components were strenuously tested and evaluated against the planned field demonstration objectives.

The support vessel (anchoring systems, winches and spuds, and deployment and retrieval systems) operations were completely successful. The shroud deployed well, the vacuum dredge and water jet were very efficient in excavating within the shroud in a variety of sediment types. The electromagnet array retrieval system operated flawlessly, meeting all project goals. The TV camera visualization system (along with the water clarification system) uniformly failed to operate adequately to identify unknown ordnance and/or to determine its fuzing. This was exacerbated by water visibility of <3 in however, the TV optics design and lighting system were also determined to be of an inappropriate design for this task. The dual-frequency identification sonar (DIDSON) imaging sonar, which might have accomplished the visual recognition tasks also failed because the plastic optics in the system had dried out and degraded from several months of non-use. There were insufficient funds available to rebuild the optical system of the sonar.

Overall, most components of the system worked well. The dredging and lifting systems were very effective during shakedown testing. This allows targets which were buried too deep for diver access to be recovered. This also reduces the amount of labor and time spent in the water by the diver. The major limitation of this technology was visualization of targets using the sonar imaging system and the video camera. The filtration system improved the water quality to visualize the object from a few inches away, but was not sufficient to identify the item or it's fuzing. Identification would require diver intervention in all cases. Improvements to the visualization system are feasible, and could be implemented in future versions. This would require additional lighting and filtration to improve target identification. We predict that the camera system would be more effective in a location with less turbid water.

2.0 INTRODUCTION

2.1 BACKGROUND

As a result of past military training and weapons testing activities, residual UXO is present at sites designated for Base Realignment and Closure (BRAC), at Formerly Used Defense Sites (FUDS), on currently-active training ranges, on private lands and marine resource and recreational areas adjacent to current and former ranges. Many of the sites associated with military practice and test ranges contain significant marine areas.

The National Defense Center for Environmental Excellence (NDCEE) has released a report reviewing and summarizing the current state-of-the-art in modern UXO remediation technologies. This report focuses upon remotely operated and automated retrieval technologies with the intent of emphasizing safety and reducing UXO recovery costs. The only technologies cited for underwater applications involve either remotely operated underwater vehicles (intended for operation at significant depths) or surf zone/beachcomber systems for shoreline applications. None of the cited approaches assumes either that digital geophysical UXO surveys have been conducted or that retrieval of specific targets with known coordinates is an objective. On shore UXO target recoveries (in benign environments) typically cost ~$200 per dug target using commercially available technologies. Recovery of the same targets in shallow water offshore costs 5-8 times more. Currently underwater UXO remediation requires hands-on, UXO-qualified diver intervention.

The currently used approach for underwater UXO retrieval requires a team of divers to manually locate and remove each individual target. The process begins with the dive team re-acquiring the target position from a boat using a hand held global positioning system (GPS). The target location is then marked using a weight and buoy or a rigid pole with a flag. An underwater metal detector is then used by a diver to reacquire the magnetic anomaly and refine the buoy placement.

Once the target is located, the diver begins the investigation and recovery process. Either using his hands or hand tools, he uncovers the item. Targets buried more than ~1.5 ft typically cannot be successfully recovered using this approach regardless of whether the bottom sediments are sand, shell, silt/mud, or clay. Divers typically use only small military-style entrenching hand tools for digging. Excavation sidewalls routinely collapse into the excavation if it is deeper than about 1 ft. Water visibility typically drops to zero once the bottom surface is disturbed. For shallower buried objects, after the target is uncovered, the diver identifies the target visually if possible, or by feel if visibility is limited. The diver, in conjunction with the UXO supervisor then determines if the item can be safely moved or whether it must be blown in place. In typical UXO marine environments, it is often impossible (or impractical) to investigate or recover more than half of the magnetic anomalies following modern digital UXO geophysical surveys.

2.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this project was to design, build, and demonstrate a semi-automated system to provide an efficient, relatively economical, and safe approach for use in recovering single UXO targets in shallow water (<15 ft). In this project, our approach has been addressed by combining technologies based upon commercial off-the-shelf (COTS) components to create an integrated system that can semi-autonomously uncover UXO buried in marine sediments, visualize the uncovered target (using TV and/or imaging Sonar), and remotely recover the target to the surface using an electromagnet or a mechanical grapple. Currently underwater UXO recovery operations typically involve explosive ordnance disposal (EOD) or commercial UXO divers precisely locating the positions of a metallic object with a metal detector, then uncovering the targets using hand tools. The identity and fuzing of the target is determined either by sight or by feel. Small targets can be brought to the surface by the diver, while larger targets require lift bags or winches to break them free of the sediment and raise them to the surface.

For this demonstration, it was our intention to use our new system to investigate and recover UXO targets from the Currituck Sound adjacent to a former test range, the Former Duck Naval Target Range. We have previously surveyed the offshore area involved in this demonstration and at the time of the original survey recovered 100 underwater targets.

2.3 REGULATORY DRIVERS

The regulatory issues affecting the UXO problem are most frequently associated with the BRAC and FUDS processes involving the transfer of Department of Defense (DoD) property to other agencies or to the civilian sector. When transfer of responsibility to other government agencies or to the civilian sector takes place, the DoD lands fall under the compliance requirements of the Superfund statutes. Section 2908 of the 1993 Public Law 103-160 requires adherence to comprehensive environmental response, compensation and liability act (CERCLA) provisions. The basic issues center upon the assumption of liability for ordnance contamination on the previously DoD-controlled sites.

The vast majority of the marine areas contaminated by UXO are in public waters. These areas may (or may have been) restricted to public access when the ranges were active. Often UXO contamination results from undershoots or overshoots of land targets. In other typical situations, marine impact areas involve public waters, which are only temporarily closed when a range is active. If the areas involved are part of the military munitions response program (MMRP) or munitions response program (MRP), the primary service responsibility is defined. In either case, CERCLA provisions apply and state and federal regulatory agencies, as well as citizen groups are stakeholders in the investigation and cleanup operations.

This project demonstration, which was originally scheduled to take place in the Currituck Sound adjacent to the former Duck Naval Bombing Range, would not have triggered regulatory issues because it is in public waters and not part of a FUDS or BRAC site. Because of financial constraints the technology demonstration took place in Jordan Lake in public waters and did not employ either inert ordnance or ordnance shapes.

3.0 TECHNOLOGY

3.1 TECHNOLOGY DESCRIPTION

The objective of this project was to design, build, and demonstrate a system, which is relatively efficient, economical and safe for recovering single UXO targets in shallow water. For the purposes of this project, we assume than an underwater UXO survey, analysis, and preparation of a target list has been completed, and that individual target positions have been reacquired for investigation and marked either with flags (very shallow water) or with weights and floats. After the targets have been marked, the recovery process begins. The target recovery process is accomplished by combining several component technologies to create a system to uncover the UXO buried in the sediment, visualize the uncovered target (using TV and/or sonar imaging), and remotely recover the target to the surface using an electromagnet or a mechanical grapple. Detailed descriptions of each of these components is provided below.

3.1.1 Spud Design and Operation

To keep the position of the recovery vessel stable along side the flag or buoy marking the re-acquired target, the vessel is positioned as shown in Figure 1. Anchor points are established and the boat position is adjusted using hand winches on the boat to adjust the length of the anchor lines.

After the workboat is positioned adjacent to the target marker, the stabilizing spuds are lowered into the bottom sediment to further stabilize the position of the vessel and keep it in place during the recovery operations. The spuds also keep the deck flat and level as equipment is deployed over the side. The spuds are constructed of square structural fiberglass tubing with flat pads mounted on the bottom. They are raised and lowered using hand winches mounted on each spud assembly. The structural fiberglass tubing for the spuds is 4” x 4” square tubing, 20 ft in length. This limited the operational depth for this demonstration to ~15 ft. An image of the vessel with the spuds deployed is shown in Figure 2.

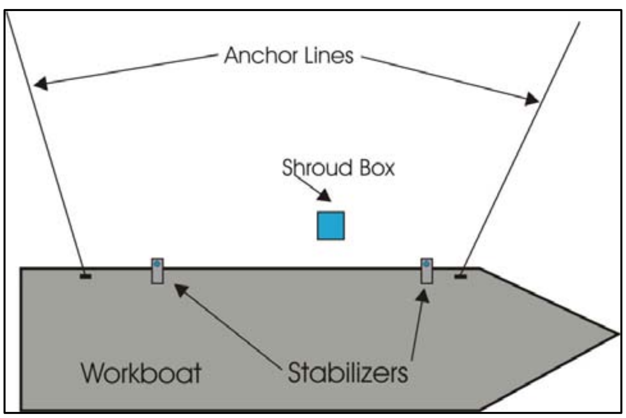

Figure 1. This is a schematic diagram showing how the support vessel is set up for a target recovery.

The mounting brackets for the spuds are bolted through the deck into the structural members of the vessel. The mounting brackets are hinged to allow them to be tilted for installation and removal of the spuds and for moving the boat between targets.

Once the boat is positioned and the spuds are deployed, the shroud is lowered into the water using the hydraulic crane (Figure 2). At this point, the recovery process begins. Two additional fixtures are used to uncover the buried target and to remove the target from the water. These assemblies are described below. The recovery vessel for this project is the 30 ft pontoon boat acquired in the marine towed array (MTA) project MM2003-24.

Figure 2. The spud assemblies are shown deployed on the recovery vessel. Note the four function crane mounted between the spuds.

3.1.2 Recovery Shroud

Once the recovery vessel has been stabilized beside the target marker, the recovery shroud is lowered over the target. A photo of the shroud is shown in Figures 3. The primary functions of the shroud are to prevent sediment from returning to the hole as it is being excavated and to prevent the excavated walls from slumping back into the hole. Additionally, the shroud provides a shield to allow the water within the shroud to be filtered to improve visualization of the target. The shroud was redesigned after an FEA modeling study as a simpler-design low cost fixture, to perform the functions described above. The shroud design is a 48 in diameter cylinder, 30 in high, with a 0.75 in wall thickness. It is a fiberglass composite weighing approximately 225 lbs. This is heavy enough to cause the shroud to settle into the hole as the sediment inside is excavated. The diameter of the shroud was made 4 ft in diameter to allow enough room for a diver (if it is necessary) to enter the shroud to examine the target before a recovery decision is made.

To assist with the positioning of the dredge assembly and the lift platform, circular fiberglass tubing is attached to the outside wall of the shroud. Long fiberglass poles are set into these fixtures. Their length extends upward beyond the water surface. The length of the tubing is adjustable, depending on the water depth.

Figure 3. The shroud is shown with the dredge assembly mounted.

3.1.3 Dredge Assembly

Once the shroud is in place, the next step in the recovery process involves uncovering and identifying the buried target. This is carried out using the vacuum dredge (Figure 4) to remove the sediment covering the target. A water jet (Figure 5) is paired with the dredge. Its function is to break up the sediment, as required. The vacuum dredge has a 4 in suction intake; an attached hose diverts the removed sediment material allowing it to be ejected well away from the work site. The dredge is designed to remove sediment at a rate of 10-12 yd^3 per hour.

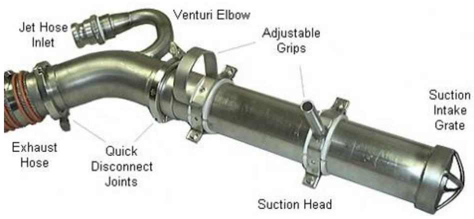

Figure 4. The Suction Dredge.

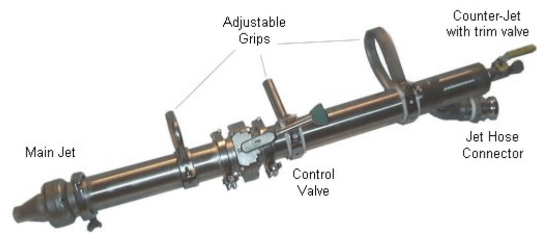

Figure 5. The Water Jet.

The dredge assembly consists of both the vacuum dredge and water jet mounted as a single unit. The handles and grips were removed from each of them and brackets were built to mount them side-by-side together so that they point at the same contact area of the sediment surface. The assembly is mounted to the side of the shroud, Figures 3.

The assembly attachment has a 3 axis rotation mount that allows the entire internal area within the shroud to be excavated. The control of the dredge assembly was originally intended to be constructed using a powered pan-tilt unit for rotation, and a hydraulic cylinder for controlling the height. Because of budget limitations, the control system was ultimately redesigned to be operated manually from the surface using three dock lines.

The vacuum dredge and the water jet are powered by a 500 gallon per minute centrifugal water pump driven by a 9 hp Honda gasoline engine. The pump is designed to sit on the boat deck. All hose connections are made using quick-connects. The same water supply powers both the dredge and the water jet. A three way valve allows water to be directed to either the dredge or the water jet individually or to both simultaneously. The water jet (adjustably) directs a stream of water both forward and backward so that the overall forces are neutralized during operation.

3.1.4 Television Camera

After completion of the dredging, the target is examined using a video camera (Figure 6) or the DIDSON system (Figure 7). The video camera is equipped with light emitting diode (LED) lights and has a fixed focus that extends from 1 in to ∞.

The DIDSON system was acquired in association with the ESTCP Project MM2003-24. Resolution of 1 cm can theoretically be achieved by this system. The imaging sonar was intended to be used as an alternative to the TV imaging system if the water cannot be filtered enough to accurately identify the target with the television camera.

Once the target has been identified and its fuzing determined using the imaging tools, a UXO-certified technician makes a decision as to whether the target can be safely recovered. If the technician determines that the target is too dangerous to mechanically recover, the target will be marked for referral to a Naval EOD Detachment for disposal. For targets that are declared as safe to recover, the target is brought to the surface using the electromagnet recovery fixture described in the next section.

Figure 6. The underwater video camera is shown. A ring of LEDs surrounds the lens.

Figure 7. This image shows the submergible components of the DIDSON Sonar Imaging System.

3.1.5 The Recovery Assembly

After the target has been uncovered, and determined to be safe to recover, the dredge assembly is removed from the shroud (to the deck of the boat) and the electromagnet recovery assembly is lowered into the shroud to capture the target. An illustration and photo of the recovery assembly are shown in Figures 8.

Two 10 in electromagnets are mounted on a spreader beam. The recovery assembly is lowered into the shroud over the exposed target. The electromagnets are activated to lift the target from the bottom surface. The recovery mounting assembly is smaller than the shroud diameter to allow side to side movement once the assembly is lowered into the shroud. This ensures that the electromagnet assembly can be located in the position required to lift the target off the bottom surface. The spacing of the electromagnets can be adjusted on the spreader beam depending on the size of the target being recovered. Targets that cannot be recovered using the electromagnets are recovered using a hydraulic grapple.

During the course of this project, on several occasions, concerns were raised about an electromagnet potentially triggering a dud fuze, which had failed to function during its initial flight and impact. We extensively addressed this issue in two separate White Papers developed during the project. Below we summarize the conclusions reached in the White Papers.

To begin with, we assert that this same type of decision must regularly made by an EOD or UXO technician each time they discover or uncover a buried ordnance item. A decision to move a target or to blow-in-place must be made for each target. The decision is made based upon the type of ordnance, its fuzing, and its overall condition. In our project the UXO technician, using the camera or sonar images determines the identity of the object, its fuzing, if it is high explosive filled, and its overall condition. The majority of UXO we encounter on bombing ranges are clearly inert: M23s, M38s, M117s, M78s/BDU33s, GP bomb shapes with no fuses, etc. If these objects can be identified on the range, they are candidates for electromagnetic retrieval. Other ordnance, such as projectiles determined to have mechanical time delay fuses, powder train delay fuses, etc., are also candidates for magnet retrieval.

Figure 8. Electromagnet Recovery System lifting an 81mm mortar.

Some ordnance however, are so badly corroded or encrusted, that it is not possible to identify them or establish their fusing. Ordnance items that cannot be precisely identified are not candidates for electromagnetic retrieval. The UXO supervisor has the option of specifying that the mechanical grapple be used to retrieve the object, that it be hands-on inspected by a diver, or that it be left in place and marked for later prearranged disposition by a Naval EOD Detachment. For the purposes of this ESTCP demonstration project it was established that no fuzed ordnance of any type would be lifted by electromagnet.

3.1.6 Shroud Development

The initial task in this project involved the development of a Safety and Environmental Risk Assessment Report on the effects to the recovery shroud of an unintentional ordnance detonation during the recovery process. The primary intended purpose of the shroud was to provide a barrier to prevent the nearby sediments from slumping into the area that is being excavated by the dredge assembly. As a secondary consideration during the initial design of the shroud, we attempted to build in design features in the shroud to provide some protection against unintended detonations by diverting some of the energy of a detonation away from the recovery vessel. To provide this protection we designed the walls of the shroud to be built of a very strong Kevlar composite and provided a ¼ in Plexiglas break-away wall in the shroud on the side opposite to the recovery vessel.

To analyze the blast affects, Mallett Technology was contracted to perform FEA simulations of various sized detonations on the shroud and the recovery equipment. These simulations were performed using Autodyn® by Century Dynamics, which is a FEA package for modeling the non-linear dynamics of solids, fluids, and gas and their interactions.

To determine the effect of an unintended detonation on the shroud during the recovery process, a series of FEA simulations was performed. The original square shroud design consisting of the Kevlar composite shroud with the Plexiglas weak wall was ineffective at diverting energy away from the recovery vessel. The shroud experienced complete failure with both ordnance sizes (0.4

lb and 4.0 lb of trinitrotoulene [TNT]). This failure was a result of de-lamination of the composite which led to complete bulk failure of the shroud. The weak wall design contributed to the failure by reducing the overall strength of the shroud design. Using the results from the square shroud simulations, the recovery shroud was redesigned using a cylindrical shape. New FEA simulations indicated that this design is predicted to survive the 0.4 lb blast without any damage. The 4.0 lb blast resulted in failure in the bottom of the shroud, although amount of damage was significantly less than was experienced by the square shroud. Figures 9 and 10 illustrate the square shroud at 9.6 ms and the cylindrical shroud at 9.3 ms after the detonation of 4.0 lb of TNT.

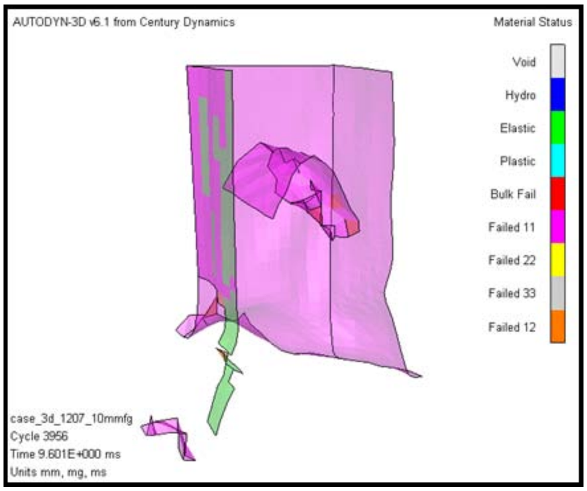

Figure 9. Square Shroud Failure Model at 9.6 ms Time Step for 4.0 lb TNT.

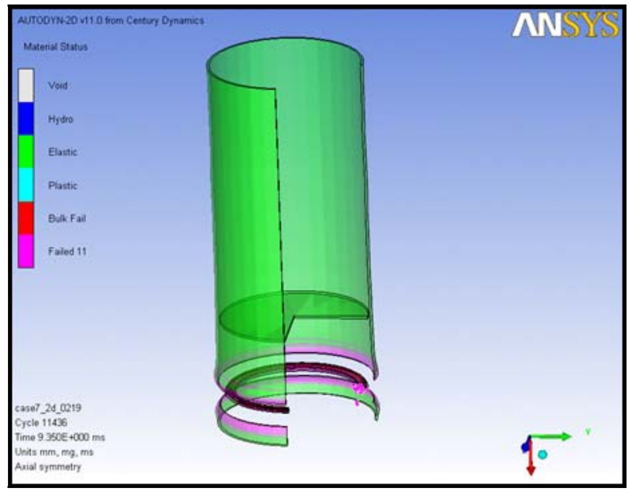

Figure 10. Cylindrical Shroud Failure Model at 9.3 ms Time Step for 4.0 lb TNT.

While the cylindrical shroud was more effective at surviving the blast, it was ineffective in containing or redirecting the pressure wave generated by the blast. Neither the square shroud nor the cylindrical shroud significantly impeded the pressure wave created by the TNT detonation. In both cases, the pressure wave reached the water surface. This pressure wave could result in damage to the recovery vessel. The likelihood and extent of the damage is undetermined because it was not part of this modeling study.

Based upon the results from the modeling study and the comments from the 2007 Winter In Progress Review (IPR), the recovery shroud was redesigned to reduce the construction costs to manufacture a shroud strong enough to prevent evacuated sediment from returning to the excavated hole. The blast protection requirement for the shroud design was eliminated. The objective of the final shroud design was to design a low cost shroud, which could sufficiently hold removed sediment away from the excavated hole. The new design was a shroud with a 48 in diameter, 30 in height, and a 0.75 in wall thickness. This shroud design weighs approximately 225 pounds.

3.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The traditional method for recovering ordnance underwater requires a team of divers (usually three divers) to manually locate and recover targets. Targets buried much deeper than 1.5 ft are difficult or impossible to retrieve because the sides of the excavated holes slump back into the excavated area. The only implement that a UXO diver typically has is a small entrenching tool.

Identification of munitions and explosives of concern (MEC) items and evaluation of their conditions is often carried out only by feel because of visibility limitations. The pay scales for UXO-certified divers are twice that of UXO-certified technicians conducting similar operations on land. Additionally, on land recovery of MEC items that do not require the use of power equipment is typically carried out by a single technician using a shovel.

The advantage of the system that we have developed is that it reduces the amount of time diver intervention is required during UXO recovery. The dredging and lifting was very effective during the shake down testing. This allows targets that were buried so deep that they could not be recovered by a diver to be accessed. It also reduces the amount of labor by the diver, and reduces the amount of time spent in the water.

The major limitation to this technology is difficulty that we have had in the imaging of the targets using the sonar imaging system and the video camera. The filtration system improved the water quality enough to visualize the object from a few inches away. This was not sufficient to view the entire target at the same time and to identify an unknown item or its fuzing. Actual identification of a target required intervention by a UXO diver on all realistic targets that we have studied. Although the visualization system was unsuccessful during the shakedown testing, improvements to this system are feasible, and can be implemented in a future version of the system. Because typical real-world ordnance items that have been in place for many years are heavily encrusted, it is unlikely that we will ever be able to completely eliminate diver intervention in all cases. However, the results from our tests indicate that the amount of dive time can be substantially reduced and that we can reach and recover many additional targets that could never be recovered by a UXO diver using typical hand tools.

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4.0 PERFORMANCE OBJECTIVES

The intent of this project was to conduct a full-scale demonstration of the technology on the Currituck Sound adjacent to the Former Duck Bombing Range. It became apparent while the Demonstration Test Plan was under development and awaiting approval that there were insufficient funds to complete the demonstration and the required final reporting documents. With approval of the Program Office, we suspended the full scale demonstration in favor of a more limited set of shakedown system evaluations on a lake near our offices. These tests were conducted using inert ordnance items from our company inventory.

Although the operations were limited in scope and we did not employ divers to support them, we set them up in a way designed to evaluate, to the extent possible, the system performance that would allow us to confidently predict the response of the system in a full scale demonstration on a former range. In the section below we discuss the system performance relative to the original performance objectives. These conclusions are based on our direct performance measurements in the lake studies and on our extrapolated predictions as to how the system would likely perform in a marine environment associated with a real target or bombing range.

The quantitative and qualitative Performance Objectives from the Demonstration Test Plan are tabulated in Table 1. For this report, the Results column has been filled in. A brief narrative description of the results is given in Chapter 7.

Table 1. List of Performance Objectives.

PERFORMANCE OBJECTIVES	METRIC	DATA REQUIRED	SUCCESS CRITERIA	RESULTS
Quantitative Objectives				
Production Rate	Operational time to set up equipment and recover a target	Field Log with recorded times for each step	Average of 1 hr recovery time per target	Estimated to be successful
Achieve Autonomous Recoveries	Complete operation accomplished without hands-on diver intervention	Record frequency and length of diver intervention for each recovery	<25% of recoveries require diver intervention	Diver required for visualization
Successful Remote Excavation	Excavation accomplished from deck of the boat	Record if target can be uncovered remotely. Estimate target depth.	Excavation and Recovery of 75% of targets buried <2 ft deep	Estimated to be successful
Remote Certification of Targets for Recovery	Ability to identify MEC Item and verify fuzing from the deck	MPEG record of target analysis	<25% of fuzing analyses require diver intervention	Targets could not be identified using camera or DIDSON
Qualitative Objectives				
Operate in Varying Weather and Sea Conditions	Demonstrate Ability to position, stabilize system, and operate at Sea State 1	Record Sea State and weather conditions for each target	Successful operation in Sea State 1 and with light rain	Unknown, all tests were completed in ideal weather conditions

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5.0 SITE DESCRIPTION

As described in Section 3.0, the system tests and demonstrations took place on two local lakes (Jordan Lake and Lake Crabtree) rather than on the Currituck Sound adjacent to the former Duck Bombing Range as was planned and described in the Demonstration Test Plan. This approach was taken, with the permission of the Program Office because there were insufficient funds remaining in the project to complete a full scale system demonstration on the Currituck Sound and to complete the required final reports.

Jordan Lake and Lake Crabtree are manmade lakes that were completed several decades ago for flood control, to support recreation (fishing, boating, and water sports), and as water supplies for the Triangle Area metropolitan centers.

Lake Crabtree is a very small body of water that was created by damming Crabtree Creek to create a local park and recreation area. It is located within one-half mile from our offices. It has a limited boat launch facility (for unpowered boats) and extensive boardwalks and decks over the water. We used the lake for testing several system components in shallow water from the decks and boardwalks. Figure 11 shows a photo of Lake Crabtree with the deck and boardwalk area that we used for component testing. Figure 12 shows an aerial photo of Lake Crabtree.

Figure 11. Dock at Lake Crabtree.

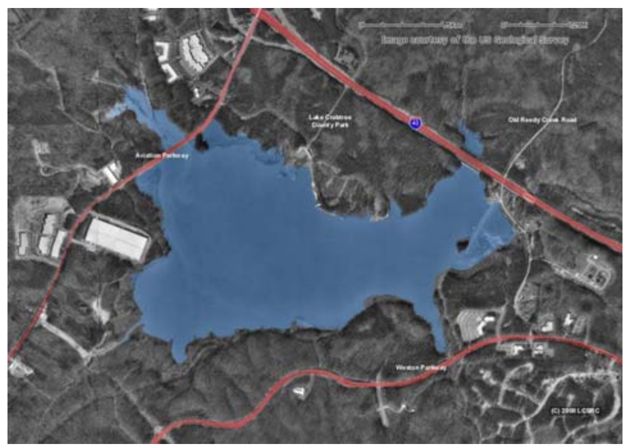

Figure 12. Aerial photograph of Lake Crabtree.

Jordan Lake is much more extensive, (Figure 13). It extends for ~10 miles in its longest dimension. Maximum water depths are ~40 ft in areas near the dam. The lake has several man-made sand beaches and about a dozen improved boat launch facilities for large power boats. The topography around each lake is fairly rugged with bedrock outcroppings and both evergreen and hardwood forests. Both lakes are primarily filled by storm water runoff following rain events. Crabtree Lake is nearly constant level; Lake Jordan water levels vary by up to several feet during the year, at least in part because it serves as a primary water supply for metropolitan areas within Wake County. Because they are primarily filled by storm water runoff each lake has a high suspended silt level and consequently very low water visibility.

Figure 13. Aerial photograph of the dam and Jordan Lake.

5.1 SITE LOCATION AND HISTORY

The full system shakedown testing was performed at Jordan Lake, in Chatham County, NC. We selected multiple locations in the lake for testing varying in depth from 4-10 ft. The majority of the testing was done in two areas of the lake. The first was in approximately 5 ft of water and the second in approximately 10 ft of water. Both locations were near the shore and had relatively flat sandy bottoms or a bottom with mixed sand and gravel. There was a relatively small amount of fine silt and leaf and mulch debris covering the sediment surface. Jordan Lake and Lake Crabtree Lake do not have any ordnance, munitions, or military-related history. The history of these sites was generally described in Section 4.0.

5.2 SITE GEOLOGY

The general site topography, vegetation and the size and shape of the marine areas have been described above. The range of water depths, sediment types, and shoreline activities have been described above. The geology of the site is not relevant to the studies that we have carried out or to this report.

5.3 MUNITIONS CONTAMINATION

There are no known munitions contamination associated with either Jordan Lake or Lake Crabtree.

6.0 TEST DESIGN

Because of a funding shortage primarily related to the extent and complexity of the FEA modeling study that was undertaken at the beginning of the project, the planned demonstration on the Currituck Sound near Duck, NC was suspended. As an alternative, tests and evaluation studies were carried out using inert ordnance items at Jordan Lake located in Chatham County, NC. The goal of the redesigned test was to evaluate the performance of the components of the system operating in a realistic setting and to determine the feasibility and likely outcomes that would have likely resulted from performing the scheduled full scale demonstration on a former target range.

6.1 CONCEPTUAL EXPERIMENTAL DESIGN

The underwater video camera and water filtration systems were developed and tested in the laboratory and were evaluated in tests at Crabtree Lake, in early October 2008.

The evaluation testing of the complete system took place in mid-October 2008. The first day was spent preparing the boat and equipment for transport. The second day was spent assembling the recovery system on the pontoon boat, launching the boat, and evaluating the performance of each of the components. Subsequently, we spent several days practicing positioning and stabilizing of the boat and operating the recovery system in deeper water.

6.2 SITE PREPARATION

No significant site preparation was required for this shakedown. Fiberglass poles were inserted into the sand to simulate target locations. This is the same method that was used during the 2006 recovery operation of the MTA on the Currituck Sound, Figure 14.

Figure 14. Divers are shown preparing to investigate a target following the 2005 MTA demonstration. Note the white flag and pole marking the target position immediately behind the skiff.

6.3 SYSTEM SPECIFICATION

The technology and the components used in the demonstration were described in part in Chapter 2 of this report. The deck of the MTA vessel was cleared of most of the equipment previously used to support the MTA survey demonstrations. The old hoist was replaced by a new 4-function marine hydraulic crane purchased from Steelhead Marine, Inc., Figure 2. This crane was used to support all the recovery operations.

The new spuds and their deployment equipment were specially constructed using local vendors and machine shops. They are installed on the deck fore and aft of the crane position, Figure 2. Both the crane and the spuds were located so that their support structures could be bolted through the deck directly into the structural members of the vessel. Mechanical winches are used to raise and lower the spuds to stabilize the boat against drifting and rolling. The mounting brackets hinge to allow them to be tilted to horizontal for installation and removal of the spuds and for transport between target locations.

There are several mounting brackets installed on the upper edge of the shroud. The most important of these is used to support the mount for the suction dredge and the water jet. The suction dredge is shown mounted on the shroud in Figure 3. This 3-axis mount allows the dredge to be rotated, tilted, and raised or lowered, to scour out sediment to uncover the target of interest. The water jet is mounted beside the dredge intake to stir up and dislodge sediment that is resistant to removal using the dredge alone.

The primary visualization tool for evaluating the target once it is uncovered is a TV camera, Figure 6. The camera is designed to mount on a pole or other external mount. It operates either in color or black and white. The image is illuminated by a ring of high brightness LEDs mounted around the camera lens. These are designed to illuminate the target.

The camera design is fixed focus and the depth of field extends from 1 inch to infinity. The camera output is visualized on a monitor screen and is recorded using a digital video recorder purchased to support the same system for the MTA. The image can be monitored in real time or reviewed during replay from the DVR. A water filtering system was designed and mounted on boat deck. It pumps clean water into the shield that isolates the area immediately in front of the camera. The shield extends forward and is intended to fit over the target being examined.

6.4 DATA COLLECTION

Because the full scale demonstration on the Currituck Sound could not be undertaken, our data collection was limited to the test and demonstration activities described above. We setup the shakedown testing at Lake Crabtree and Jordan Lake to provide the best evaluation of the system performance under the limited scope of operation. Using the results from our shakedown testing, we have described what we feel that the actual performance would be under full scale recovery operations in the field.

6.5 VALIDATION

N/A

7.0 ANALYSIS PLAN

7.1 PREPROCESSING

N/A

7.2 TARGET SELECTION FOR DETECTION

The shakedown demonstrations on Lake Crabtree and Jordan Lake were setup to evaluate (to the extent possible in these limited studies) the performance of all components of the system in a way that would allow us to accurately predict actual performance in a full-scale field demonstration on a former marine ordnance range. We evaluated all the components of the system using inert ordnance items and ordnance surrogates placed on the sediment surface. We worked in water depths ranging from 4 to 10 ft. We tested the dredge/water jet on both sandy bottoms and bottoms with sediments of mixed sand and gravel.

Because of the limited scope of the tests that were carried out we were unable to evaluate the overall system performance as a function of varying water surface conditions and in weather conditions that were less than ideal.

The limiting effects on the system performance were the extremely poor water visibility and the limitations of our TV imaging system (and the DIDSON sonar imaging system) in overcoming these limitations. A rebuild of the DIDSON system optical components and a redesign of the TV camera (and water clarification systems) would improve the system capabilities for operating in extremely turbid water.

7.3 PARAMETER ESTIMATES

N/A

7.4 CLASSIFIER AND TRAINING

N/A

7.5 DATA PRODUCTS

The primary data products of this project are the narrative description the system operation as described in previous sections. Because the demonstration was limited to evaluation studies and testing at local lakes, accurate predictions of production rates, and system limits cannot be quantified with confidence. Estimates based on our results indicate that the recovery of a single UXO item can be completed in under 1 hour, and that the dredge can successfully uncover targets buried at least 2 ft deep.

8.0 PERFORMANCE ASSESSMENT

8.1 OBJECTIVE: PRODUCTION RATES

The metric for measuring the production rate, was the operational time to setup the equipment and recover a target. The goal was to recover targets in less than 1 hour. Because the targets were not buried during the shakedown testing but were instead placed proud on the bottom, we were unable to complete an actual recovery of buried objects. We used the dredge to excavate an area representative of that required to recover a target buried between 1 and 2 ft deep. The actual amount of dredging required could be more or less depending on the target depth and size; and the time required may strongly depend upon the sediment composition.

The other unknown is the visualization of the target. The camera and filtration system were unsuccessful in identifying targets in water (with 3-6 in visibility) in separate experiments at both Jordan Lake and Lake Crabtree. We assembled equipment to filter the water and inject a clear stream directly in front of the camera. We developed a shroud that fit around the camera that was designed to be lowered over the target of interest. The clear water stream was introduced into the shroud beside the camera. This approach allowed us to image a 2 to 3 in diameter area of the target. We could identify dummy fuzes that were screwed into different color inert ordnance items. However, we felt that it was unrealistic to expect that the required identifications could be made on encrusted old ordnance without being able to simultaneously image the entire ordnance and to then focus in on the fuze components. Hence, we decided that it was likely not possible to make the required target and fuzing identification using this camera visualization system in an environment like Currituck Sound, which also has typical water visibility of about 6 in. Without additional improvements to the visualization system diver intervention would be required on each target to make the necessary identifications and to determine if the target was safe for recovery. Although there are still unknowns, based upon the successful operation of all the other system components, we expect that a straight forward target recovery could take place in under 1 hour, in good weather conditions.

8.2 OBJECTIVE: AUTONOMOUS RECOVERIES

The metric for autonomous target recoveries, was to complete the recovery operation without hands-on intervention from a diver. We concluded that it would not be possible to identify realistic targets in very turbid water with the video camera or sonar imaging system as they are currently designed and currently operate. Diver intervention would be required for all target identification for conditions equivalent to those in our lake studies. We anticipate the camera system would be more effective in clear water with greater visibility. We were unable to evaluate this premise in our limited demonstration. Replacing the current camera with a new camera with a wider field of view and with a much more intense lighting system will be required before the system is retested. Rebuilding the DIDSON optical system may also provide a separate potentially powerful visualization approach. Available funds were not sufficient to support the repair.

8.3 OBJECTIVE: SUCCESSFUL REMOTE EXCAVATION

The metric for successful remote excavation was that all excavation activities using the suction dredge and water jet could be completed from the deck of the boat. This was a success. The three axis mechanical rotation allowed the suction head to be easily manipulated inside the recovery shroud. The manual design using dock lines was easily operated by one person. The three way ball valve allowed for both simultaneous and individual operation of the suction dredge and water jet. The water jet was effective at breaking up crusty sediments, allowing the suction dredge to remove and eject material away from the recovery area. In several instances excavations were made greater than 2 ft deep. The system was most effective when the water jet was operated individually for periods of time applying the full pressure from the pump to break up the sediment. The ball valve was then switched to simultaneous operation to excavate the sediment away from the area.

8.4 OBJECTIVE: REMOTE CERTIFICATION OF TARGETS FOR RECOVERY

The metric for remote certification of targets for recovery required identification of MEC items and their fuzing from the deck of the boat. This was unsuccessful in the turbid water at Lake Jordan and Lake Crabtree. The filtration system was able to provide enough clean water to allow the target to be visualized from a few inches away. This did provide enough view to confidently identify a real unknown target and to determine its fuzing. Additional filtration and lighting are required for this to be successful. We expect the current camera system would be much more successful in clear water.

8.5 OBJECTIVE: OPERATE IN VARYING WEATHER AND SEA CONDITIONS

The metric for operating in varying weather and sea conditions was to demonstrate the ability to position, stabilize and operate the system at sea state 1 with light rain. During the shakedown testing, we did not experience any waves, rain, or significant wind. The water was flat the entire operation. We were unable to evaluate the system in other weather conditions. We confidently predict, however that the spud system would maintain the boat in a stable configuration in sea state 1 conditions. The presence of a light rain would make little or no difference to any of the operations associated with this project

9.0 COST ASSESSMENT

9.1 COST MODEL

In Table 2 we present the Cost Model for a hypothetical project using the equipment developed for this demonstration. The costs are based upon either the original equipment purchase costs for items provided as government furnished equipment (GFE) from other ESTCP/SERDP projects, the costs of components (or their development costs if they were constructed in house) developed in this project, rental costs based upon recent rental experience, and support services costs is based upon recent experience. The equipment costs are listed at their full development or replacement value; no attempt is made to develop an amortization schedule or a plan to capitalize these costs. This cannot be realistically done until there is a reasonable estimate of the probable business use for the equipment. Additional assumptions associated with the Cost Model are provided below.

- Equipment costs are based on full replacement value, or are the full manufacturing costs for one-of-a-kind components. The components in Table 2 are those that we had available (some from prior projects and some from SAIC property inventory). They would not necessarily be the same components that would be used if a new (most appropriate) system were being created for commercial purposes. The “commercial” system would be considerably less expensive than the value quoted in Table 2.
- Mobilization and demobilization costs are based upon a 500 mile round trip (Cary, NC to the destination). It is assumed that a one day pack out will be required before departing Cary. The mobilization day is assumed to include travel and unpacking of equipment. It is assumed to take 1.5 days to recover all equipment, dismantle, and pack out in preparation for return to Cary. Rental vehicles are assumed to be returned the following day.
- Site preparation costs are assumed to include only the costs for reacquiring and flagging targets to be recovered. It is assumed that GPS-based first order control points were previously established in support of the recovery operation. No costs have been assumed for vessel launching and recovery, for slip fees, or for equipment loading and unloading, (which would be required if equipment were shipped to the site by common carrier).
- Projected costs for the UXO-certified diver are based upon the assumption that he will not be diving. Actual dive time will be additionally charged at twice the quoted hourly rate. UXO-certified technician costs are based upon the total daily fractional costs to the subcontract and include mobilization, travel, rental vehicle, per diem costs. The diver travel is assumed to be 400 miles round trip by private vehicle.
- The explosives demolition costs are based upon a small number of items (~25) and assume that all functions can be handled by the UXO technician alone. The costs of the demolition will be a strong function of the shipping distance for the explosives, local explosives storage costs, and shipping costs for residue disposal.

- The costs of the recovery operation are quoted on a per day basis. There are no economies of scale unless the water operations extend beyond two weeks. This hypothetical operation assumes that the work week consists of six 8-hour days. One day is charged at overtime rates. For multi-week operations costs must be adjusted for weekend time off, weekend overtime, weekend travel costs, and/or for crew change out costs.

Table 2. Cost Model for a Field Recovery Operation using the Automated Underwater Retrieval System.

	COST ELEMENT	KNOWN COST ($K)	TRACKING DATA
Equipment Costs	GFE Equipment		Assumes use of ESTCP equipment from inventory
	Pontoon Boat	22.9	
	GPS Equipment	20.0	
	Sonar	3.5	
	Electronics	20.0	
	Sensors	12.0	
	Build-Out Pontoon Boat		Based upon development costs
	Components	43.0	
	Engineering	10.0	
	Custom Fabrications	4.5	
	SAIC-Owned Equipment		Assumes use of SAIC-Owned equipment from SAIC inventory
	Skiff, Engine, Trailer	10.0	
	GPS Equipment	23.0	
	Magnetometer	20.0	
	Hardware	2.0	
	Consumables	2.0	
	Repairs	3.0	
Total Support Equipment Costs		**195.9**	
Mobilization/ Demobilization	Rental Equipment	3.0	Assumes 8 day rentals
	Travel Costs	0.3	Assumes 500 mi round trip
	Labor/Per Diem	16.7	Daily Costs
	Marinas, Moorings	0.2	Assumes 1 week mooring
Site Preparation/ Setup Costs	Target Reacquisition/Flagging		Assumes 1 day to reacquire all targets
	Labor/Per Diem	4.3	
	UXO Tech Support	1.2	
	Hardware	1.0	
	Chase Boat	0.2	
	Position Refining		
Recovery Costs/ Per Day On Site	Labor/Per Diem	4.3	Number of targets recovered days on site
	Chase Boat	0.2	
	Rental Vehicles	0.4	
	Fuel	0.1	
	UXO Tech Support	1.2	
Daily Operational Costs		**6.1**	
Demonstration Consumables	UXO Demo Costs	2.0	Assumes 1 demo, 1 day
	Explosives	3.0	
	Waste Disposal Cost	3.0	
	Equipment Repairs	4.0	
	Consumables	3.0	

9.2 COST DRIVERS

The primary cost drivers for implementing this technology on a demonstration site are water depth, water clarity, target depth, and target type. On a range with fairly clear water (good diver visibility), fairly deep water, and primarily inert ordnance it is likely that using a dive team will be the more economical approach for routine target recoveries. The previous sentence basically described the situation at the Proof Testing Range on Lake Erie at Port Clinton. Even at this range, however, there were ~20% of the targets that were not recovered because the diver could not touch them to determine fuzing, or could not break them loose from the sediment. These targets would be clear examples appropriate for the use of this approach. On Lake Erie, in the diver-only recovery operation typically 18-24 targets were recovered per day. The recovery operation was conducted by two 3-man dive crews in 2 boats with an additional UXO-supervisor. Recovery rates were much lower when prosecuting targets in the Toussaint River. This technology would be most beneficial on a range with shallow (< 10 ft) water, and deeply buried targets.

9.3 COST BENEFIT

The cost benefit of this system is unknown at this point. It is doubtful that this system would be more economical than a dive team on a site with good visibility and primarily inert ordnance. This system has a significant benefit in recovering targets buried too deep for divers to access. Such targets are currently left in place, and reported to the local EOD detachment for prosecution.

10.0 IMPLEMENTATION ISSUES

The major obstacle to future implementation of this system is with underwater visualization. This proved to be a more difficult task than originally anticipated. The water filtration system improved the water clarity enough to allow the target to be visualized from a few inches. This did not provide an extensive enough view of the target to allow for identification. For this system to be successfully operated in the field, the visualization must be improved. This should be accomplished with additional filtration, additional lighting, improved camera design and/or a rebuilt sonar imaging system.

Overall, the system was straightforward to operate. Positioning the vessel was easily accomplished using winch controlled anchors. The mechanical winches were effective at raising and lowering the stabilizing spuds. The 4 function hydraulic crane allowed the shroud to be positioned efficiently over the marked target. The dredge was easy to manually control using the dock lines. Completing automation of the dredge/water jet system would improve its operation. A hydraulic controlled system would improve the positioning of the suction head and water jet, and allow for more efficient dredging. The electromagnet was able to lift the inert items used in the shakedown tests. We do not know how effective it would be at lifting larger partially buried items.

All components used to construct this system were either COTS or easily manufactured items. No special skills or training is needed to operate the technology. A UXO technician/diver is required at all times during operation if ordnance items are potentially going to be encountered. The technician is responsible for making and implementing decisions related to identification and recovery of all UXO items.

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APPENDIX A

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